Art. XVII.—*The High Frequency K Series Absorption Spectrum of Erbium.*

By L. H. MARTIN, B.Sc.

(Communicated by Professor T. H. Laby).

(With one Text Fig.)

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A critical absorption "edge" in the X-ray spectrum of an element has a wave length such that the element absorbs X-rays of shorter wave length than that of the edge, more than X-rays of longer wave length.

For the heavier elements we find one such edge in the K series, three in the L series, and five in the M series[1].

It is found experimentally[2] that if the element previously used as an absorber is now used as a target in an X-ray tube, the K series of this element are emitted only when the voltage applied to the electrodes of the tube equals, or is superior to V_K given by the quantum relation,

$$h\nu_K = \nu_K e$$

where $h = 6.556 \times 10^{-27}$ erg. sec. $e = 1.591 \times 10^{-20}$ e.m. C.G.S. units and ν_K is the frequency of the critical absorption edge, which is also greater than the frequency of the shortest K emission line i.e.,

$$\nu_K > \nu_K\gamma > \nu_K\beta > \nu_K\alpha > \nu_K\alpha' \quad (3) \text{ where } \nu_K\gamma\ \nu_K\beta\ \nu_K\alpha\ \nu_K\alpha'$$

are the frequencies of the K emission lines.

In virtue of these facts, critical absorption phenomena have assumed an important significance in the physical model of the atom as developed by Kossel, Bohr, Sommerfeld, and Wentzel. They are expressions of "levels" of energy within the atom.

It is found that we can form a table of the frequencies of these absorption edges [K; L_1 L_2 L_3; M_1 M_2 M_3 M_4 M_5, etc.] the frequency of every X-ray emission line being expressed as the difference of the frequencies of two edges properly chosen[4], every emission line corresponding to a definite pair of energy levels. We have for example:—

$$K\alpha = L_1 \rightarrow K \qquad L\alpha = M_1 \rightarrow L_1$$
$$K\beta = M_3 \rightarrow K \qquad L\beta = M_2 \rightarrow L_2$$

by which we mean, that the frequency of the K_α line equals the difference between the frequencies of the L_1 and K critical absorption edges, or in terms of our atomic structure, the K_α line is emitted by an atom when an electron falls from the L_1 electron shell to the K electron shell.

The aim of X-ray spectroscopy is then to compile a table of the frequencies for all the critical absorption edges of each element rather than tables of emission line wave lengths. Sommerfeld[5] proposes to call such a table (values of ν/R when R is Rydberg's frequency 3.29×10^{15} sec -1) a "term" table. This table will contain for the heavier elements $1(K) + 3(L) + 5(M) + 7(N) + 5(O) = 21$ "terms," from definite combinations of which we can determine the values of ν/R for every emission line for each element.

Up to the present terms for elements of atomic numbers $61 \rightarrow 73$ have not been measured, and the purpose of this paper is to show how the K "term" of erbium ($N = 68$) was determined; soon it is hoped to be able to give the K "terms" for the remaining earths.

X-Ray Spectroscopy.

The analysis of an heterogeneous X-ray beam into its homogeneous constituents is made possible by the "three dimensional" grating formed by the arrangement of the atoms in a crystal. Calcite was chosen as grating crystal because of its relatively large reflecting power, and because it is easier to obtain a calcite crystal which is a perfect X-ray grating than a rock-salt crystal. The grating space "d" is such that with the spectrometer used, the K_α $K_{\alpha'}$ lines of tungsten ($\lambda K_{\alpha'} - \lambda K_\alpha = 4.81 \times 10^{-11}$ cm.) are resolved with a slit width equal to .12 mm.

A full description of an X-ray spectrometer, similar to that used, was given by Mr. Rogers in these Proceedings, May, 1922, so that here, only those modifications will be described which have been added in an attempt to increase the accuracy of the determinations, and facility with which the apparatus can be used.

The wave length of the erbium K critical absorption edge is approximately $.217 \times 10^{-8}$ cm., so that Bragg's fundamental equation for the diffraction of X-rays by a crystal,

$$\lambda = 2d \sin\theta \quad \ldots\ldots\ldots\ldots \quad (1)$$

can be written, since the angle of reflection of this wave length amounts to approximately 2°.

$$\lambda = c.\theta \quad \ldots\ldots\ldots\ldots \quad (2)$$

i.e., the wave length is proportional to the angle of reflection.

When photographing the K absorption edge the crystal was made to oscillate about its axis through 7 mins. of arc by means of a cam driven by an electric motor and reduction gear. This was necessary, as exposures of nearly seven hours were required to obtain a suitable photograph of the edge.

A crystal holder was designed so that the crystal could first be made vertical and then brought into the axis of rotation. In fig. 1. (a) the crystal C is held rigidly by a piece of rectangular tubing A, supported by the main carrier B, at the three points B_1, B_2, B_3, by loosely fitting bolts, rigidity being obtained by three very stiff springs, S_1, S_2, S_3.

The crystal can be brought into the vertical by adjustments of the hexagonal nuts N_1, N_2, N_3, B rests on three ball bearings, two of which move in a V groove, and the third on a flat; the crystal being moved along these, by means of a fine thread screw engaging the carrier B.

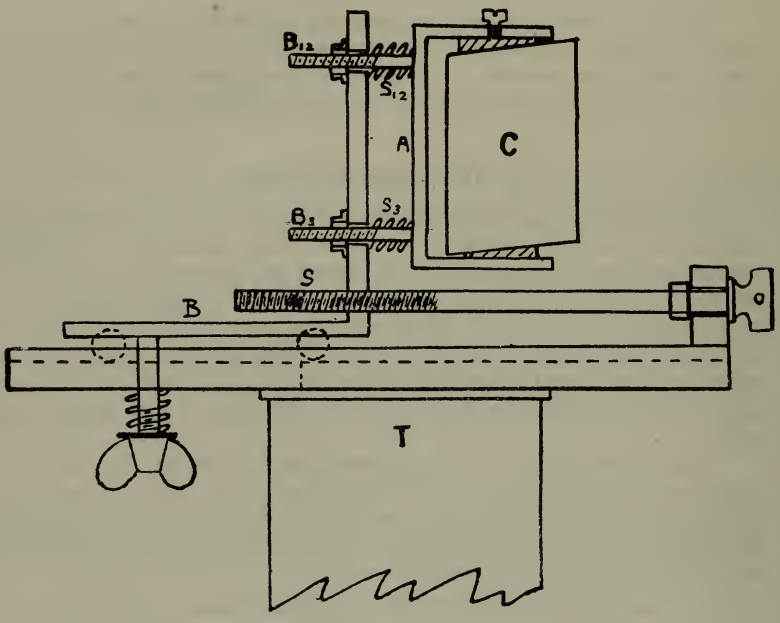

Fig. 1 (a)

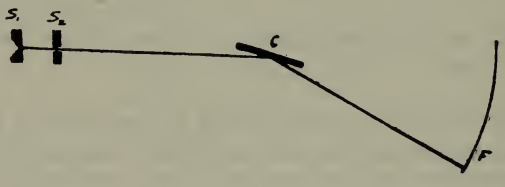

Fig. 1 (b)

Fig. 1 (b) is a diagramatic representation of the disposition of the apparatus. The tube slit S_1, which serves as a fine linear source of X-rays was usually .06 mm. wide. The second slit S_2, serves to limit the angular width of the incident beam. The edges of this slit move in parallel grooves and were arranged parallel to S_1, and symmetrical about S_1, by an optical method.

Adjustments.—The plane of the tube slit S_1 was first adjusted by an optical method to be perpendicular to the radius O S_1 (Fig. 1.) and at the same time vertical.

A reflected image of S_1 was observed in the polished crystal face. The crystal was adjusted as explained above so that the slit S_1 and its image were parallel for all positions of the crystal.

To set the surface of the crystal in the axis of rotation a fine needle point, lying horizontally opposite the middle of the crystal, was observed by a long focus microscope. The needle was adjusted until the point did not move in the field of view when the table was turned through 360° The crystal was brought up until the reflection of the point, and the point itself, just touched when seen under the microscope. In this manner it was possible to set the crystal rapidly so that its middle section coincided with the axis of rotation to within ± .0005 cm.

In order to ensure that the central ray from the target passes through the axis of rotation, the crystal was set at zero and an X-ray photograph taken of the crystal. If the setting of the target is true, the edge of the crystal lies exactly in the centre of the darkening, which is limited by S_2.

Experiment.— As the erbium K absorption edge could not be distinguished from the $K\alpha'$ line of tungsten, it became necessary to use a Gundelach gas tube with a platinum target as a source of general radiation.

Two millimetres thickness of erbium oxalate were placed before slit S_1, and the absorption edge registered on one half of the film, while the reference tungsten $K\alpha$ $K\alpha'$ lines were placed on the other half. The distances $W_{K\alpha} \rightarrow Er_{K\alpha}$, $W_{K\alpha} \rightarrow W_{K\alpha'}$ were measured by projecting the film (magnification 10) on to a vertical platform, motions of which could be read by a dividing engine screw accurately to .0005 mm. Table I. contains an actual series of displacement measurements.*

TABLE I.

$W_{K\alpha} \rightarrow W_{K\alpha'}$.	$W_{K\alpha} \rightarrow Er_{K\alpha}$.	λEr_K × units.	$W_{K\alpha} \rightarrow W_{K\alpha'}$.	$W_{K\alpha} \rightarrow Er_K$.	λEr_K × units.
mm.	mm.		mm.	mm.	
1·513	2.353	216-08	1·497	2·346	216·14
1·523	2·398	215·96	1·488	2·343	216·17
1·524	2·386	215·99	1·503	2·349	216·12
1·514	2·356	216·09	1·508	2·358	216·12
1·515	2·366	216·09	1·497	2·363	216·19
1·512	2·350	216·07			

* The method, suggested by Professor Laby, developed in this laboratory for measuring these small displacements has been described previously by J. S. Rogers, M.Sc. (l.c.).

The values $W_K\alpha = 208.60 \times 10^{-11}$ cm., $W_K\alpha' = 213.41 \times 10^{-11}$cm. are those of W. Duane and W. Stenstrom[6], which lead to a value for the erbium K absorption edge.

$$\lambda Er_K = 215.9 \times 10^{-11}\text{cm.}$$

Pl. 2.	Oct. 24.	$\lambda = 216.09 \times$ units.	Weight 1.
Pl. 4.	Nov. 16	$\lambda = 215.85 \times$ units.	Weight 2.
Pl. 5.	Nov. 21.	$\lambda = 215.87 \times$ units.	Weight 2.

Weighted mean $\lambda = 215.9 \times 10^{-11}$ cms.
Term value (ν/R units) = 4222.

Discussion.

In the determination of the wave lengths of such penetrating rays as the above, we are beset with the difficulty, that, owing to crystal penetration the effective plane of reflection lies below the surface of the crystal. If θ is calculated from the geometrical properties of the apparatus, and the distance of "edge" from direct ray impression, an error is introduced amounting to nearly 3% in short wave length determinations. Errors of this magnitude are observed in the K absorption edge determinations of de Broglie[7] for elements Hg to U.

In this method, which might be called a method of coincidences, the reference rays and the erbium K absorption edge have sensibly the same wave length, and the result is free from this objection.

Determinations have been made by Duane and Blake[8], using an ionisation chamber method in which θ was read directly from an accurately divided circle, and by Siegbahn and Jonsson[9], using a photographic method, both of which are free from the above source of error. Siegbahn and Jonsson used their crystal as a transmission grating, a method first devised by Rutherford[10] for his determinations of the wave length of the penetrating γ rays of RaC, the rays being constrained by slits to meet the plane of reflection passing through the axis of rotation.

Although both methods are free from objection, the values obtained by Sieghahn and Jonsson are systematically smaller than those obtained by Blake and Duane for the absorption edge wave lengths of the K series.

Extrapolating the two series of values for the value expected for erbium we find—

Siegbahn and Jonsson	$\lambda = 215 \times 10^{-11}$ cm.
Blake and Duane	$\lambda = 216 \times 10^{-11}$ cm.

The value found here 215.9×10^{-11} cm. agrees better with the results of Blake and Duane. Duane has suggested that the discrepancy may be found in that Siegbahn probably measured from the point at which darkening began, instead of the point corresponding to the centre of the slit. Here that settings were made for those rays which correspond to the centre of the slit.

I wish to thank Professor Laby for his valuable advice and interest during the execution of this work. I am also very much indebted

to Welsbach and Co., U.S.A., for a very pure sample of erbium, which they presented to the Natural Philosophy Dept. X-ray analysis showed that there was no discernable impurity.

References.

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